



A Measurement of the Neutron and Gamma Transmission of a Protective Vest

by Samuel F. Trevino

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14. ABSTRACT <p>The thermal (meV) and energetic (MeV) neutron transmission of a protective vest is measured. The vest is provided by the National Ground Intelligence Center. The energetic neutron transmission of 0.51 (0.025) was measured with the neutrons from an AmBe source. The thermal neutron transmission of 0.0034 (0.00017) was measured with the neutron activated prompt gamma instrument Prompt Gamma Activation Analysis. The numbers in parentheses are one standard deviation. Both of these instruments are located at the National Institute for Standards and Technology Center for Neutron Research. Additionally, the following isotopes were found, by delayed gamma emissions after neutron adsorption, to exist in the sample: ⁶⁶Cu, ⁵⁶Mn ²⁴Na ⁶⁵Zn, and ⁶⁰Co. Quantitative amounts of these were not determined. No nuclei specific for neutron protection (boron, lithium, and cadmium) are found in sufficient quantities for the purpose. The gamma ray transmission of the sample is also measured. Several natural radioactive sources producing gamma rays in the energy range from 60 to 1250 keV are used. The transmission varies from ~0.6 to 1 for the lowest to the highest energy gamma rays.</p>					
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1. Introduction

A vest, presumably designed for protection from nuclear radiation, is investigated for effectiveness. A possible use of the vest is the diminution of exposure to neutron and gamma radiation. For this purpose, the transmission of both energetic (MeV) and thermal (meV) neutrons and gamma rays are measured.

2. Experimental

The vest consists of several “pockets” of the shielding material enclosed by a canvas type material. The size of each pocket is $\sim 50 \times 50 \text{ mm}^2$ and 25 mm thick. A photograph of the vest is shown in figure 1. The composition of neither substance, the shielding or enclosure, is known. Two instruments are used in the transmission measurement of neutrons. These serve for the determination of the transmission of the material for energetic and thermal neutrons. Several natural radioactive sources of gamma rays are used to determine gamma transmission as a function of energy.



Figure 1. The vest under investigation.

2.1 Energetic Neutrons

The energetic neutrons are obtained from an AmBe source of ~ 1.8 Curies activity. The several measurements¹ of the spectrum of these neutrons is shown in figure 2. The measurement of the spectra of energetic neutrons is not an easy task. This is reflected in the several spectra in the figure obtained by different methods, each of which has a different efficiency vs. energy. This source produces energetic neutrons by natural radioactive processes. As such, the energies of the neutrons reflect resonances characteristic of the nuclei. These resonances are clearly detected by

¹ Report 13; International Commission on Radiation Units and Measurements: Bethesda, MD; pp. 20–21.

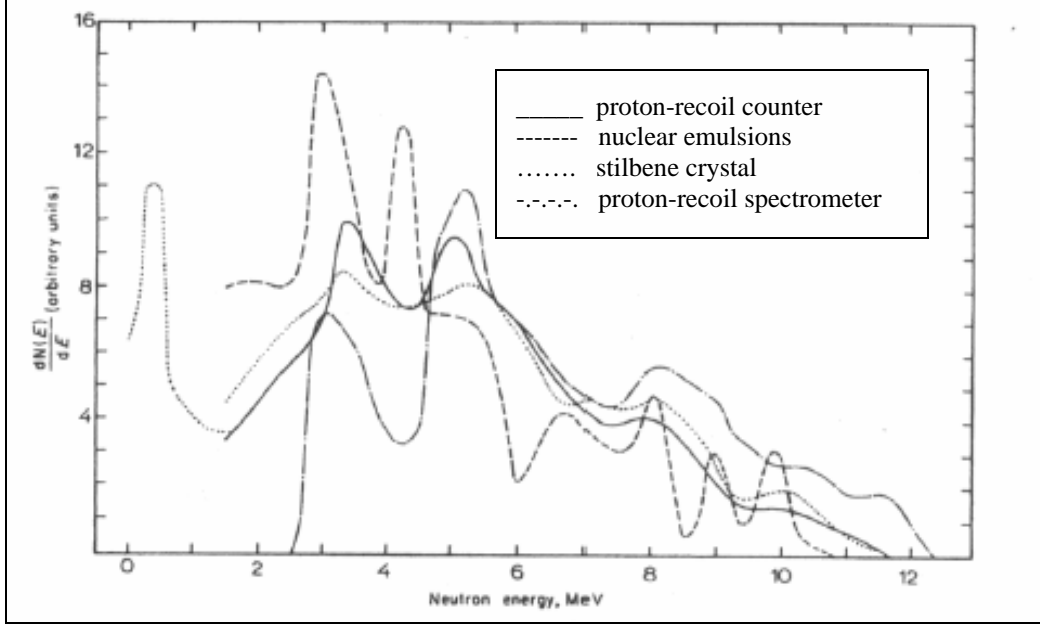


Figure 2. The various measurements of the spectra of neutrons from an AmBe source.

all the methods used in their characterization, although not in the absolute intensities. This is the state of the art in these measurements. The source is contained in a cylindrical cavity coincident with the cylindrical axis of a cylindrical barrel of paraffin. The cavity is 35 mm in diameter and 530 mm in depth. The barrel of paraffin is 610 mm in diameter and 870 mm in height. The top of the barrel is covered with a 0.5-mm-thick cadmium sheet. This precaution is taken to reduce the neutron background produced by the thermalization of the neutrons by the paraffin of the barrel. Measurement determined that 30% of the counting rate off center was due to thermal neutrons. The detector is a cylindrical proportional counter with a 16-mm diameter and 25 mm long-filled with BF_3 (with 96% ^{10}B) to a pressure of 600-mm Hg. It is housed in a 76.2-mm diameter plastic sphere. This is a standard configuration for the measurement of energetic neutrons. A measurement of the detected neutrons as a function of the detector position with respect to the cavity is shown in figure 3. The distance d is measured along a line perpendicular to the cylindrical axis. The solid line is a Gaussian function,

$$I(d) = (I_0 / \sigma \sqrt{2\pi}) \exp(-[(d - d_0) / 2\sigma]^2), \quad (1)$$

representing the energetic neutron flux and a linear function $(81 + 0.038d)$ representing the “background,” d in centimeters. This linear function is found to faithfully describe the “background” near the peak. Here, I_0 is the integrated intensity, σ is the standard deviation, and d_0 is the peak position with respect to the nominal zero. I_0 is taken as the incident flux for the purpose of the transmission measurement. The value of $\sigma = 2.7$ cm corresponds to a full width at half maximum of ~ 5.86 cm. This width is adequate to cover a substantial portion of one of the pockets of the vest.

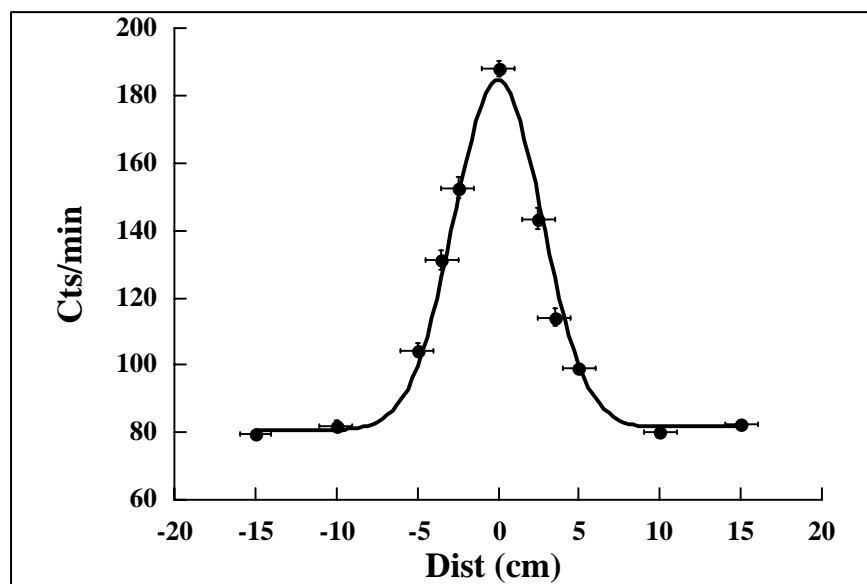


Figure 3. The spatial distribution of neutrons from the energetic neutron source. Zero represents the nominal position of the collimated energetic neutron beam.

2.2 Thermal Neutrons

The thermal neutron source is the research reactor of the National Institute for Standards and Technology Center for Neutron Research (NCNR). This research reactor operates at 20 MW thermal. It serves as a source of thermal and cold neutrons for materials research. The instrument used in this investigation is the Prompt Gamma Activation Analysis (PGAA) facility located on a vertical beam line V5. The spectrum of neutrons is well described by a Maxwell-Boltzmann distribution characterized by an equilibrium temperature of ~ 300 K (the temperature of the heavy water reactor moderator). This spectrum² is displayed in figure 4. The PGAA instrument is designed to measure the gamma rays emitted promptly by a material after absorption of a thermal neutron. Figure 5 is a schematic of the instrument. A sample whose prompt gamma spectrum is to be measured is placed in the “prompt gamma sample position.” The sample is illuminated with the vertical thermal neutron beam. The Ge detector measures the gamma ray spectrum emitted, after capture of the neutrons. The energy of the gamma rays is characteristic of the absorbing isotope. If well calibrated, their measured intensity may be used to determine the abundance of that isotope. In the present measurement, a sample of boron carbide (BC) in a graphite matrix is used as the “sample.” The natural isotopic abundance of ^{10}B and its adsorption cross section of ~ 4000 b is sufficient to produce measurable results of the reaction

² Williams, R. NIST Center for Neutron Research. Private communication, 2005.

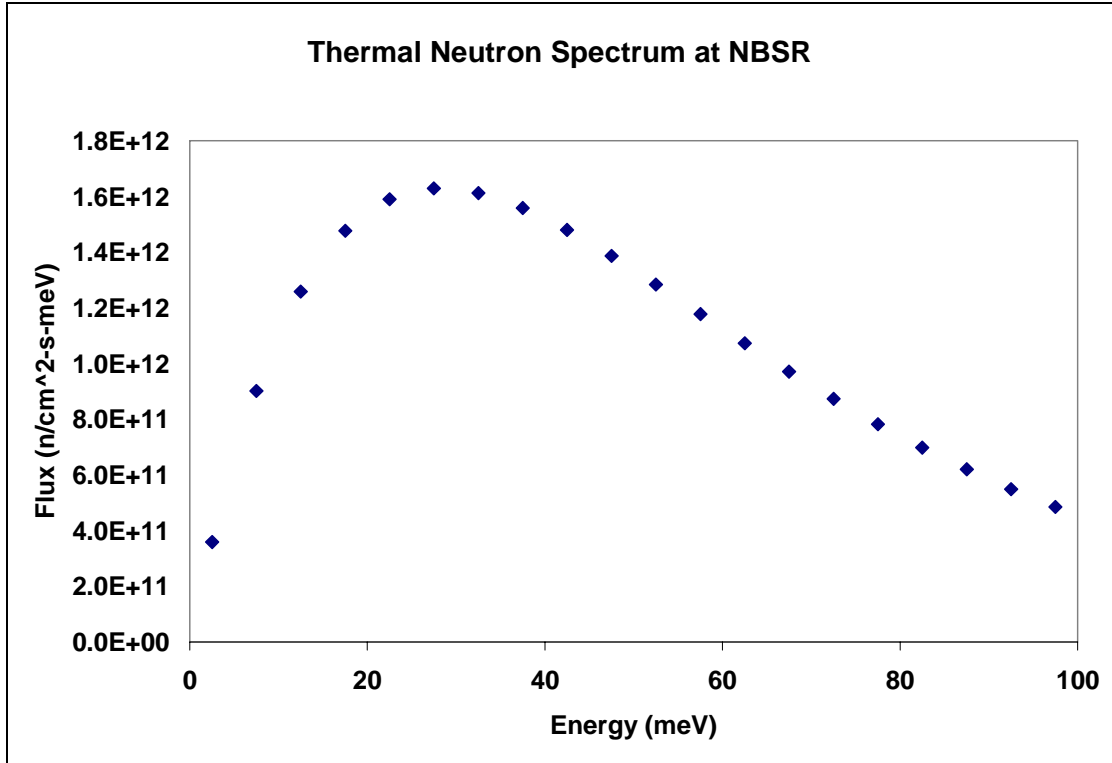
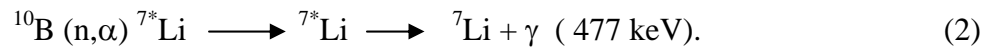


Figure 4. The thermal neutron spectrum from the NCNR research reactor.



The $^7\text{Li}^*$ isotope is in an excited state that promptly decays by the emission of the 477-keV gamma ray. This detected gamma intensity is well correlated with the incident flux of neutrons on the sample. It is now a matter of measuring this gamma intensity with and without the sample in the “transmission measurement sample position.” The collimation before the sample produces a neutron beam with an 11-mm diameter, substantially smaller than the pocket. The transmission sample is well below the collimator defining the entrance to the detector. This prevents any signal emanating directly from the sample from reaching the detector. As a precaution to ensure that no signal from the sample contaminated the detector when the sample was in place, a spectrum was obtained with the vest in the sample position.

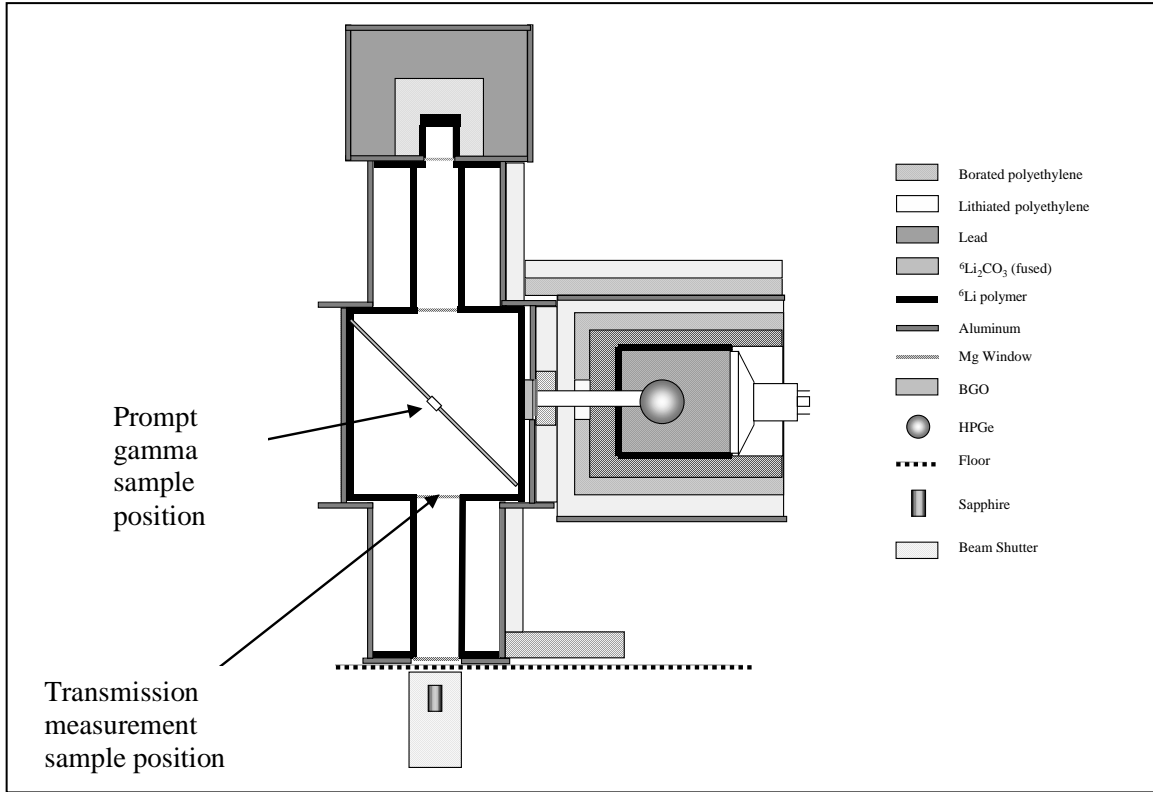


Figure 5. A schematic of the PGAA instrument used to measure the thermal neutron transmission.

2.3 Gamma Ray Transmission

Several sources of gamma rays were used in this measurement. These are listed in table 1, which contains the energy of the emitted gamma ray. A Victoreen model 451P pressurized ion chamber was used to detect the gamma rays. The source and detector were juxtaposed with enough distance between them to introduce the vest. Transmission measurements are accomplished by determining the detection rate with and without the vest between the source and detector. Errors in the measured intensity were estimated by noting the fluctuation of the count rate during the measurement. These errors were of order 5%, quite adequate for the present.

Table 1. The measured gamma ray transmission of the vest.

Source	Gamma Energy (keV)	Transmission
^{241}Am	59.5	0.61
^{235}U	186	0.75
^{137}Cs	662	0.88
^{60}Co	1252	1

3. Results

3.1 Energetic Neutrons

Figure 6 shows the spatial distribution of the neutrons detected by the energetic neutron instrument as a function of position with respect to the central channel. This is with the sample covering that channel. Again, the background is approximated by a linear function ($88 + 0.55d$) of d and the signal with a Gaussian. The parameters that result from the fit are given in table 2. The ratio of integrated intensity with the sample to that without is 0.51 (0.025). The number in parentheses is one standard deviation.

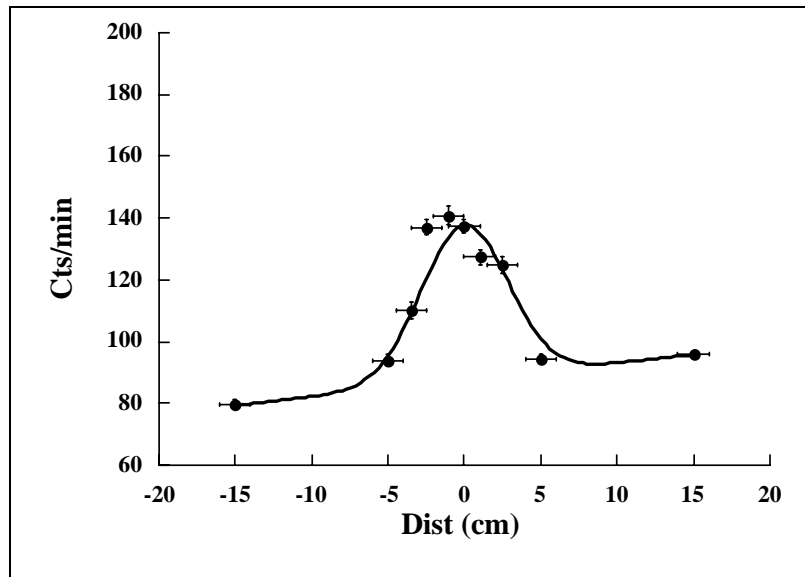


Figure 6. The spatial distribution of neutrons from the energetic neutron source with the vest centered over the channel. Zero represents the nominal position of the collimated energetic neutron beam.

Table 2. The parameters of the Gaussian fit to the spatial distribution of energetic neutrons. (The numbers in parentheses are one standard deviation.)

	I_0 (cts/s)	d_0 (cm)	σ (cm)
No sample	700 (15.5)	0.0 (0.057)	2.7 (0.052)
With sample	357 (15.4)	0.0 (0.11)	2, 84 (0.11)

3.2 Thermal Neutrons

The spectra of gamma rays was obtained with the vest in the sample position. This measurement is not intended to produce absolute quantities of the various isotopes in the sample. In order for that, a careful measure of the total mass of sample must be known. It is, however, possible to indicate the presence of various isotopes. This may still be of some use. Hydrogen and carbon were readily detected with the prompt gamma detector. Delayed gamma activity, measured shortly after exposure to the thermal neutron flux, indicated the presence of ^{66}Cu , ^{56}Mn , ^{24}Na , ^{65}Zn , and ^{60}Co . These were easily detected. Their existence reflects the presence of the isotope of each material of atomic number one less than the radioisotope detected (these having been produced by neutron adsorption). The absence of other isotopes from this list does not indicate their absence from the sample. The ratio of the flux of the 477-keV gamma ray with and without the sample in the beam is 0.0034 (0.00017) and is therefore the transmission of thermal neutrons.

3.3 Gamma Ray Transmission

Table 1 contains the result of the gamma ray transmission measurement. The data is also plotted in figure 7. The resulting energy dependence is quite reasonable.

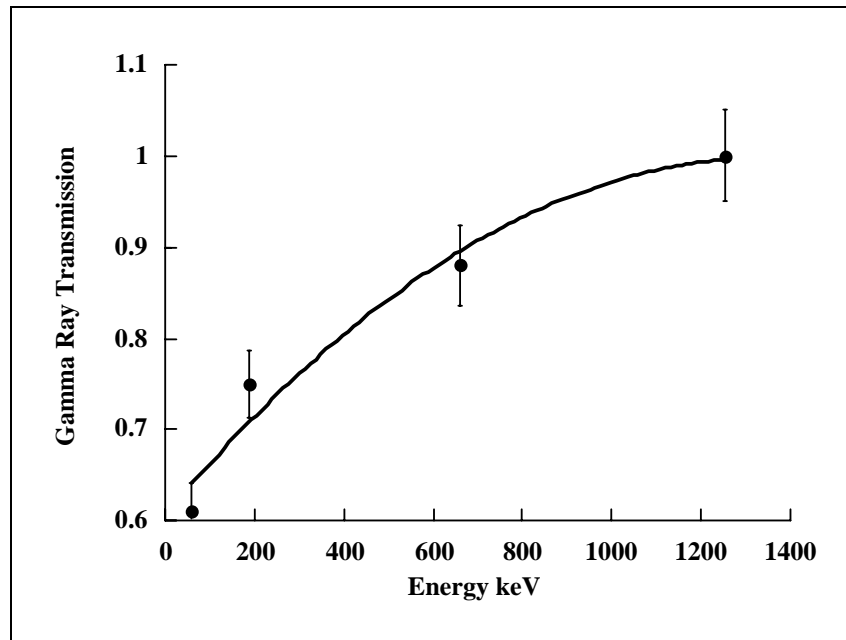


Figure 7. The gamma ray transmission of the vest as a function of gamma ray energy. The line is a guide to the eye.

4. Conclusion

This ratio of energetic neutron to thermal neutron transmission, ~ 150 , is quite reasonable. It is not surprising that the transmission of thermal neutrons is so small considering the thickness of the material. However, as a protective device, this transmission is not small enough. For example, a flux of thermal neutrons of 10^9 neutrons/cm²/s produces a dose of 1 rem. Health Physics considers a safe dose to be 0.5 mrem/hr. This would require a transmission of $\sim 1.4 \times 10^{-5}$, substantially smaller than 3.4×10^{-3} . There is also no detection of nuclei specific for neutron protection (boron, lithium, and cadmium). If this is designed for neutron protection, it is poorly done. The gamma ray transmission measurements also do not reflect any extraordinary properties for radiation protection. This material is not well suited to protect the human body from these radiations.

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